Third
Semi-Annual Status Report

Grant NGR 03-002-122

"Astrometric and Astrophysical Investigations of Comets, Minor Planets, and Satellites"

1 February 1968 - 31 July 1968

Elizabeth Roemer
Principal Investigator

Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721

OBSERVATIONS

Observing time with the 61-inch NASA reflecting telescope of the Lunar and Planetary Laboratory was scheduled for two or three nights near each new moon during the report interval for astrometric observations of comets, minor planets, and satellites. Except during February, when bad weather interfered, each observing run was at least partly successful. To take advantage of the exceptional opportunities offered by the close approach of the minor planet (1566) Icarus to the earth (to within 0.04 astronomical units), many extra nights were scheduled in June, most of them jointly with A.M.J. Gehrels, for intensive astrometric and photopolarimetric observations of this unusual asteroid. A few observations of newly discovered comets were obtained with the 7-inch Bailey astrograph of the Steward Observatory, University of Arizona.

Statistics of the observations are as follows:

Number of nights		25
Number of plates obtained		106
Number of objects:		
Planetary satellites	3	
Minor planets	9	
Periodic comets	5	
Near-parabolic comets	4	
		21

Satellites	Minor Planets	P/Comets	Parabolic Comets
Jupiter X	(433) Eros	Borrelly	1967n Ikeya-Seki
Jupiter XII	(1362) Griqua	Wirtanen	1968a Tago-Honda-Yamamoto
Neptune II (Nereid)	(1566) Icarus	Schwassmann-Wachmann 1	1968b Whitaker-Thomas
	(1647) Menelaus	Schwassmann-Wachmann 2	1968c Honda
	(1685) Toro	Perrine-Mrkos (not found)	
	(1727) 1965 BA		
	(1733) 1938 DL 1		
	(1746) Brouwer		
	1948 EA (not found)		

The observations of Icarus are of special interest because of the unusual character of the orbit of this object. Only nine asteroids have been observed to move in orbits that cross closer to the sun than the orbit of the earth, and only three of these asteroids have been observed long enough that their future positions can be reliably predicted. Icarus has the most extreme orbit of the nine, with perihelion well inside the orbit of Mercury ($q = 0.19$ a.u.), semimajor axis comparable with that of the earth ($a = 1.08$), extremely high eccentricity ($e = 0.82$), and fairly high inclination ($i = 23°$). Each of these earth-crossing minor planets can approach close to the earth at intervals that correspond to integral multiples of the periods of the earth and the minor planet. For Icarus this interval is 19 years (19 $P_{\oplus}$ = 6940 days; 17 P_{Icarus} = 6948 days). The circumstances in 1968 resembled closely those of 1949, when Icarus was discovered after the close approach was past. The minimum separation of earth and minor planet of 0.04 a.u. in 1968 was nearly the smallest possible. At the next approach, in 1987, the minimum separation will be appreciably greater.

The 1968 close approach of Icarus presented the first opportunity at which radar observation of an asteroid appeared feasible. At best, the strength of the return signal was expected to be only marginal for detection. In order to have the best possible range and range-rate data, optical observers were asked to make every effort to obtain accurate positions of Icarus in advance of the time of closest approach on June 14. Because of the difficult position of Icarus with respect to the sun, optical detection could not be expected more than a few days in advance of the close approach. Although the observations were made difficult by the faintness and rapid apparent motion (24' per hour) of the object, coupled with bright moonlight, the necessary measurable plates were obtained by us on the morning of June 11 with the 61-inch Catalina reflector. The observed coordinates of Icarus were communicated by telephone and telegraph the same afternoon. The only other pre-approach position was obtained by S. Vasilevskis on the evening of June 11 (P.D.T) with the 20-inch Carnegie astrograph of the Lick Observatory. These positions were in excellent internal agreement, showing that only a small orbit correction was required; the correction was, however, crucial to the success of the radar experiment. With the aid of the optical data, radar returns were obtained both at Goldstone and with the M.I.T. Haystack antenna. (<u>Physics Today</u>, Sept. 1968, p. 75; <u>Science</u>, **162**, 903, 1968)

The close approach of Icarus also presented unusual opportunities for physical observations by more conventional methods. Proximity to the earth caused the asteroid to be much brighter than usual, and a large change in both aspect and phase angle occurred as the object passed by the earth. Determination of both the color and polarization dependence on phase angle gives information on the character of the reflecting surface. The amplitude of the light curve of a rotating body of irregular shape depends on the angle between the direction of observa-tionsand the direction of the pole of rotation. For Icarus the phase angle (the angle between the earth and sun as seen from the planet) changed from 83° on June 15 to 40° on June 23, the interval covered by the highly successful photopolarimetric observations of A.M.J. Gehrels and his group. Assistance in locating Icarus was rendered to the photopolarimetric observers on many nights. This aid in detection and identification became particularly important as the object faded and the rate of motion decreased. It was possible to continue astrometric observations until August 15, by which time Icarus had faded to magnitude 20. Our observations on June 11 and on August 15, supported by this NASA Grant, represent both the first and the last observations of Icarus obtained anywhere at the exceptional 1968 close-approach apparition. A joint report of our observations, by A.M.J. Gehrels, E. Roemer, R. Taylor, and B. Zellner, is being prepared for submission to the Astronomical Journal.

As previously, eye-estimates of the brightness of cometary nuclei and of minor planets have been made regularly by comparing the astrometric plates with standard exposures on several Selected Areas in which faint stellar magnitude sequences have been calibrated photoelectrically.

MEASUREMENT AND REDUCTION OF ASTROMETRIC OBSERVATIONS

Measurement of photographic plates and reduction of accurate positions have proceeded in parallel with the observational work, with the assistance of Mrs. Barbara Schreur.

Statistics for the report period:

Plates measured	64
Plates reduced	49
(Plates with insufficient reference stars	24)

Reductions make use of reference star positions from the various sections of the Astrographic Catalogue and are run routinely on the CDC 6400 of the Numerical Analysis Laboratory of the University. For some fields, too few catalogue stars are available, even from the Astrographic Catalogue, within the limited field of the long-focus reflector. (The Astrographic Catalogue contains coordinates of more than 12 million stars, in contrast with the Smithsonian Star Catalog, which contains only some 258,997 stars compiled from the best zone catalogs.) To reduce positions of moving objects in sparse star fields, the positions of secondary reference stars have to be determined with respect to stars of known position on plates that encompass a wide field. A suitable program is being written for the CDC 6400 computer for reduction of positions of secondary reference stars from plates taken with any astrographic telescope. The present plan is to use the Bailey astrograph of the Steward Observatory to obtain the field plates for the necessary two-step reductions.

Observations that are immediately useful in orbit determinations have been communicated to the I.A.U. Central Telegram Bureau, located at the Smithsonian Astrophysical Observatory, for rapid publication in the Circulars, and, in various cases, positions have been communicated to especially interested individuals as well. Positions of the newly discovered comet 1968 a, Tago-Honda-Yamamoto, and of the close-approach minor planet (1566) Icarus were made immediately available in this fashion. Positions of the faint tenth Jovian satellite were communicated in advance of formal publication to P. Musen (Goddard Space Flight Center), who is studying its motion as an example of a general perturbation method. Descriptive data concerning comets in 1967 was furnished to Brian G. Marsden for the important summary report on cometary activity published each year by the Royal Astronomical Society (Quarterly Journal R.A.S. 9, 304, 1968).

ASTROPHYSICAL PROBLEMS OF COMETS

Graduate students have undertaken from time to time investigations of various astrophysical problems concerning comets as part of individual problems courses under my supervision. Charles M. Snell is now examining the observational evidence regarding "disappearing" comets as the basis of the research report required for his M.S. degree. His investigation includes: 1) Study of the nature and significance of various kinds of reported nuclear activity, 2) Examination of any correlation between classes of activity and subsequent fading or disruption of the comet, and 3) Establishment of disintegration rates separately for periodic and near-parabolic comets, with the aim of detecting any significant differences.

Snell's study bears on the widely accepted suggestion by J. H. Oort that comets now come from a comet cloud at great distance from the sun. To obtain agreement with the observed frequency distribution of $1/a$, a high disintegration rate seems to be required for comets deflected into the inner solar system from the cloud for the first time. The correctness of such a disintegration rate was argued by A. J. J. van Woerkom on the basis of failure to recover a number of expected periodic comets, coupled with the fading during observation of several near-parabolic comets. The picture has changed significantly in recent years, however, with the careful orbit studies of periodic comets, particularly by B. G. Marsden. Several "long-lost" periodic comets have been recovered, and there is reason to be optimistic regarding eventual reobservation of several more "lost" comets. Inadequate searches and faulty predictions for returns have been shown to be more more important than fading as the reason for failure to observe the comets at missed returns.

Snell is making use of Edgar Everhart's recent efforts to establish the true population of near-parabolic comets, freed of the bias introduced by observational circumstances of discovery. The plan is to determine how much fading is necessary to explain failure to reobserve an appropriate fraction of "new" comets on subsequent returns, and then to consider whether the determined amount of fading is consistent with observations of real near-parabolic comets before and after perihelion passages.

Incidental to a trip to the East Coast (at no cost to NASA or the University of Arizona) to attend the meeting of the American Astronomical Society in Charlottesville, Virginia, early in April, I conferred with Dr. A. Delsemme of the Department of Physics and Astronomy of the University of Toledo regarding physico-chemical problems of cometary nuclei. For some time there has been a major difficulty with the observed rate of evolution of cometary gases, considering the dissociation and ionization energies of parent molecules, the surface area of the nucleus, and the available energy. The new nuclear radii, which depend on photographic photometry from our high-resolution astrometric plates, on which the nucleus is well distinguished from the coma, have led to much smaller surface area than formerly, and consequently a much better agreement. Dr. Delsemme has now in mind laboratory investigation of physico-chemical parameters of appropriate molecules at low temperature and pressure to attempt to improve values that are now extrapolated from very different conditions.

On the same trip, I also visited Goddard Space Flight Center to confer with Drs. Bertram Donn and Jürgen Rahe regarding the atlas of structural features of cometary heads, to which reference was made in the preceding Status Report. Agreement has been achieved on the basic organization of the first section of the atlas, and selection of illustrations is in progress.

SCHMIDT TELESCOPE

Further study has shown that the plan to use for the new Schmidt telescope the mounting and drive of the existing 21-inch reflecting telescope, which has been used almost exclusively for photoelectric photometry, is not desirable. The use of the Schmidt telescope for photographic exposures that cover a wide angular field and are long in duration compared with the time that a star must be kept centered in the diaphragm for a photoelectric measure, imposes appreciably more stringent requirements on accuracy of the drive and small flexure of the mounting than is of concern for photoelectric photometry. The dome is not overly large to accommodate the Schmidt, and use of the existing asymmetrical mounting would force an off-center position of the telescope. Such a situation would accentuate problems of clearance between the telescope and dome as well as access of the observer to the telescope in certain positions.

A symmetrical mounting will minimize flexure problems, and it appears that either a bent yoke, or a saddle on a straight yoke can give a satisfactory solution to the problem of limited access to the pole that is characteristic of the yoke design.

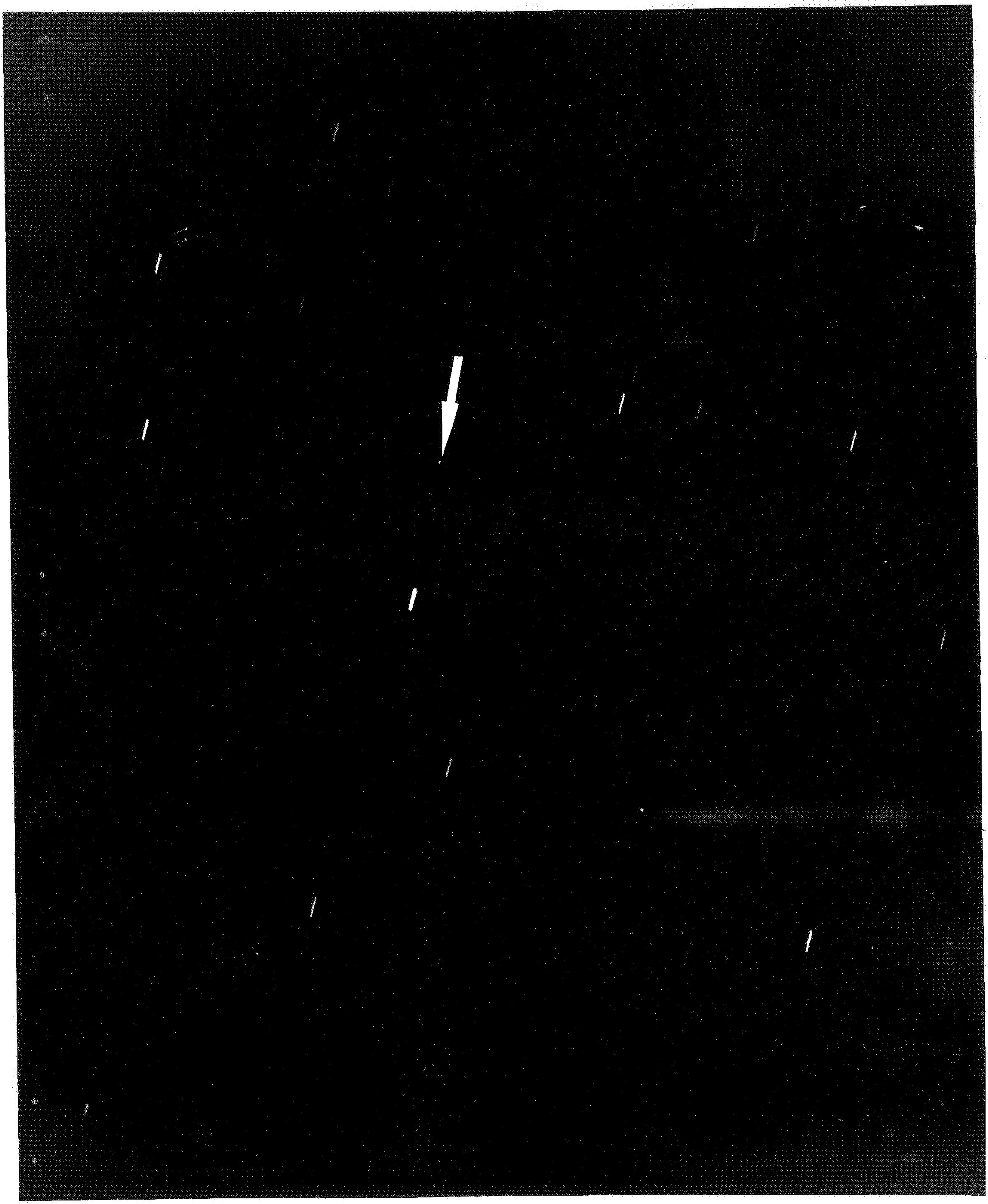
We expect to proceed with a new yoke-type mounting, including a new drive with larger gear wheel. It is anticipated that funding will be available from non-NASA sources. Unfortunately, some difficulties have led to a delay.

The need for the Schmidt telescope remains as great as ever, and we are proceeding with engineering matters of the camera itself until the problems connected with the mounting are resolved. It may be of interest to note that actual experiments have proved that standard 16 x 16-cm, 0.040-inch thick glass plates can be bent with negligible breakage to the necessary radius of curvature for use in the Schmidt. Use of glass plates is obviously preferable to film in most applications that we have in mind.

Elizabeth Roemer

CAPTION

The close-approach minor planet (1566) Icarus as photographed on June 27, 1968, with the 61-inch NASA reflecting telescope of the Catalina Station of the Lunar and Planetary Laboratory. The exposure was 10 minutes on Kodak 103aO Spectroscopic Plate. At the time of this observation Icarus was distant 0.21 a.u. and of photographic magnitude about 16.5. The rate of motion had decreased to only 61' per day. The print is enlarged from an original scale of 10"/mm to about 6"/mm.



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

LUNAR AND PLANETARY LABORATORY

Astrometric Observations of (1566) Icarus
made with the 61-inch reflector
of the Catalina Station

Station Coordinates: λ $7^h\ 22^m\ 55^s.68$ west of Greenwich
ϕ $+32°\ 25'\ 00''.4$
h 2517 meters (preliminary)

1968 UT		α (1950.0)			δ			Obs/Meas
June 11.43059		4^h	03^m	$14^s.70$	$+64°$	$50'$	$30''.9$	R, C; R
11.43823		4	03	25.03	+64	54	05.1	R, C; R
17.16470		14	52	32.08	+17	00	30.9	R, G; S
17.16678		14	52	32.83	+16	58	57.8	R, G; S
19.15500		15	01	23.43	- 0	00	53.6	R, G; S
19.15708		15	01	23.82	- 0	01	35.7	R, G; S
21.21120		15	05	58.00	- 8	41	03.4	R, Z; S
21.21329		15	05	58.22	- 8	41	26.0	R, Z; S
26.15988		15	11	53.68	-17	41	08.8	R, S; S
26.17169		15	11	54.14	-17	41	54.6	R, S; S
27.20089		15	12	47.39	-18	42	59.5	R, S; S
27.20922		15	12	47.71	-18	43	27.2	R, S; S
July 2.17018		15	16	40.09	-22	00	27.1	R, H; S
2.19449		15	16	40.91	-22	01	08.8	R, H; S
Aug. 15.15624		15	59	10.31	-29	00	03.3	R, S; R
15.20277		15	59	13.58	-29	00	14.4	R, S; R

R = Elizabeth Roemer
C = Arthur E. Clements
G = A. M. J. (Tom) Gehrels
S = Barbara Schreur
Z = Benjamin Zellner
H = Alika K. Herring

Elizabeth Roemer
September 17, 1968

EARTH-ORBIT-CROSSING ASTEROIDS

		a	e	i	q	Q	Status
1566	Icarus	1.078	0.825	23°0	0.19	1.97	Secure
1620	Geographos	1.244	0.336	13.3	0.83	1.66	Secure
1685	Toro	1.382	0.443	9.6	0.77	1.99	Secure
	1959 LM	2.155	0.675	7.6	0.70	3.61	
	1950 DA	1.695	0.506	12.2	0.84	2.55	
	1948 EA	2.261	0.605	18.4	0.89	3.63	
	Hermes = 1937 UB	1.29	0.48	5	0.67	1.91	Lost
	Apollo = 1932 HA	1.48	0.56	6	0.65	2.31	Lost
	Adonis = 1936 CA	1.97	0.78	2	0.43	3.51	Lost

NEAR EARTH-ORBIT-CROSSING ASTEROIDS

		a	e	i	q	Q	Status
	1953 EA	2.44	0.58	20.3	1.03	3.86	Recovery possible
	1960 UA	2.24	0.53	4.	1.05	3.43	Recovery possible
	1968 AA	2.15	0.50	24.	1.07	3.22	Recovery possible
1221	Amor	1.92	0.44	11.9	1.08	2.76	Secure
1627	Ivar	1.86	0.40	8.4	1.12	2.60	Secure
1580	Betulia	2.20	0.49	52.0	1.12	3.27	Secure
433	Eros	1.46	0.22	10.8	1.14	1.78	Secure
887	Alinda	2.52	0.54	9.1	1.15	3.88	Secure?

THE ASTRONOMICAL JOURNAL

PUBLISHED BY THE AMERICAN INSTITUTE OF PHYSICS
FOR THE AMERICAN ASTRONOMICAL SOCIETY

VOLUME 73 1968 March (Supplement) ~ No. 1357 *NUMBER 2, PART II*

Abstracts of Papers Presented at the 125th Meeting of the American Astronomical Society, held 4–7 December 1967 at the University of Pennsylvania, Philadelphia, Pennsylvania

Dimensions of the Nuclei of Periodic and Near-Parabolic Comets. ELIZABETH ROEMER, *Lunar and Planetary Laboratory, University of Arizona.*—The preliminary results on dimensions of cometary nuclei reported earlier by the author (*Mém. Soc. Roy. Sci. Liège*, 5th Ser., **XII**, 23, 1966) have been extended on the basis of homogeneous photometric data to include practically all comets under observation in the interval April 1957 through October 1965.

The 42 observed periodic comets show a sharply peaked frequency distribution of nuclear radii with maximum frequency corresponding to a radius of about 3.5 km for assumed albedo 0.02 (0.6 km radius for albedo 0.7). The frequency distribution of nuclear radii for 24 near-parabolic comets is much flatter and extends from radii of 2 km to more than 60 km for an assumed albedo of 0.02 (radii 0.3 to 10 km for albedo 0.7). Nuclei of all the observed periodic comets of perihelion distance less than 1.5 a.u. were small, while progressively larger nuclei were found among periodic comets of larger perihelion distance. Both large and small nuclei were found among the near-parabolic comets that came to perihelion inside the orbit of Mars. The four observed near-parabolic comets with the largest nuclei all moved in orbits with perihelia more distant than 2 a.u.

The populations of the two dynamical classes of brighter comets, for which discoveries may be essentially complete, appear to be similar, the cumulative number N of comets with nuclei larger than radius R being well represented by a function of the form $N=N_0R^{-s}$. The population index s of both the periodic and near-parabolic comets, considered separately, was determined to be near 1.5. Various inferences can be drawn from the population statistic regarding possible albedo changes, the apparent scarcity of large nuclei among periodic comets, and the deviation from a power law representation for faint comets.

The new work reported here was supported under NASA Grant NGR 03-002-122.